SSPC 62 PROPOSED STANDARD 62-1989 REVISION:

The Use of Literature Emission Rates for the Calculation of Alternate Ventilation Rates (AVR) in Indoor Environments for Acceptable Indoor Air Quality.

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Introduction

ASHRAE Std. 62-89 "Ventilation for Acceptable Indoor Air Quality" specifies ventilation rates for a variety of indoor environments that will be acceptable to 80% of the occupants. The standard is primarily one of comfort. ASHRAE does not claim health protection in the standard. This is evidenced by ASHRAE's stated goal to "specify indoor air quality that is acceptable to human occupants and intended to avoid adverse health effects. For substantive information on health effects, the Standard must rely on recognized authorities and their specific recommendations" (Std. 62-89, pg. 1). ASHRAE's definition of acceptable indoor air quality is "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority of the people exposed do not express dissatisfaction" (Std. 62-89, pg. 3). Thus, for health based standards, ASHRAE's Std. 62-89 defers to other authorities and standards.

ASHRAE's SSPC 62 is currently revising Std 62. Part of the proposed revision includes an alternative ventilation rate (AVR) procedure to be used in determining the required ventilation rate

in an environment with expected strong sources. This portion of the standard appears to be primarily health based. Its purpose is to prevent the accumulation of substances in an indoor environment at concentrations above those published in the draft Table C-1a. At present, there appear to be several deficiencies in the AVR procedure.

The AVR procedure depends on: 1) a list of emission rates, provided in the draft Table H-1, 2) a list of target indoor air concentrations, provided in Table C-1a, and 3) an equation which will use these two values to calculate a required ventilation rate.

Table C-1a Values

The concentrations published in Table C-1a do not appear to be based on those needed to protect occupants' comfort or health. They simply appear to be the lowest standards which can be found for the substances listed. Holcomb has written a white paper regarding Table C-1a which outlines these concerns and suggests more realistic values.

AVR Equation

The AVR procedure, when used to predict the necessary ventilation rate in a typical office environment generates ventilation rates which are several times those currently specified for office environments under Std. 62-89 or proposed under the current revision.

Alternatively, when the AVR equation is used to calculate resulting indoor concentrations from given emission rates and ventilation rates it generates predicted indoor concentrations higher than those found in real indoor environments. This is demonstrated in Appendix A. Since the concentrations predicted by this method are substantially higher than those found in real world environments it must be concluded that either the values in Table H-1 are inaccurate or that the AVR equation does not represent the effect of HVAC systems in real buildings.

Table H-1 Emission Rates

The values in Table H-1 cover only a small portion of potential indoor sources and emitted substances. Because of the possible inaccuracies in Table H-1 and the narrow range of values provided, an independent search of the literature was conducted to determine as many emission rates as possible. The results of this literature search are summarized in Table 1. The emission rates from Table 1 are tabulated by product category in Table 2.

Table 3 is a list of each product, the type of emission that is reported, the range of emission rates which has been published and a single value which is believed to be representative of that product and range of emission rates. The range of published values is believed to represent a wide range of potential products and product formulations. The age of the products tested varies considerably but, in general they are believed to be fairly new.

The range of emission rates is also believed, to some extent, to be the result of unstandardized testing protocols. The single value chosen is believed to be indicative of a less than new product that is not in the high end of emissions for that product category. It is believed to be a rough estimate of a mean emission rate assuming that the values in the range are log-normally distributed.

Table 4 is the list of products and emission rates from Table 2 after they have been normalized to square meters of office floor space using the assumptions listed in the back of Table H-1. These values can be compared to those published in Table H-1 as is shown in Table 5.

The range of emission rates of a given substance from a given product generally spans approximately three orders of magnitude. While the representative value chosen was an attempt to select a value likely to occur in a real environment, the range is wide enough so that changing this value by a factor of two or three would produce a new value which is equally valid. This could result in a potential range of required ventilation rates (or predicted indoor concentrations) that could span a factor of four to six, a small range in relation to those which are possible but a large range in regard to predicting potential indoor exposures.

All of the data collected are derived from chamber tests. Test protocols for these do not appear to be standardized to any degree.

Test chambers vary in size and design. The choice of emissions to be monitored varies. The specific product to be tested and the age of the product can vary markedly. In addition, chambers differ markedly from real world environments. Whole building HVAC systems are much different than ventilation in a test chamber. Sinks exist in buildings which are not present in test chambers.

The papers reviewed indicate that emissions drop fairly rapidly with product age. The length of product aging during the tests ranged from approximately 24 hours to approximately one week. The drop in emission rate was generally between a factor of 3 - 50. This drop, however, is small in relation to the overall range of emission rates reported. Thus, while it is possible to predict a drop in the indoor concentration of a substance due to the aging of a source, it would be hard to predict what the actual beginning and ending concentration may be.

Data also suggest that emission rates increase with increasing ventilation rates (see studies 2, 3, 18, 22). Specifically, for formaldehyde, emission rates are stated as being a function of ventilation rates, formaldehyde concentration in the air and loading factors (m^2 of product per m^3 of space). Baechler et al. (1989) reports that VOC emission rates are also affected by ventilation rates, temperature and humidity. They also discuss the difficulty of attempting to compare emission rates from different

studies due to this. Thus, published emission rates may be more dependent on test conditions than product characteristics.

It can be observed that, while emission rates from a fairly wide range of products are available, the bulk of the data are limited to TVOC and formaldehyde emission rates. Formaldehyde may not be a valid substance with which to attempt to predict needed ventilation rates due to its tendency to increase emission rates in response to increased ventilation rates. The lack of a recognized TVOC criteria concentration makes this group of substances inadequate for determining necessary ventilation rates. Other substances which are associated with indoor air quality (e.g., particulates) have little emission rate data which can be used to help determine needed ventilation rates.

Of all the products for which emission rates were found, two categories of products stood out for having very high emission rates: wood finishes and consumer products (i.e., waxes, cleaning products, deodorizers). Most emission rates were in the $10 - 10^2$ $\mu g/m^2$-hr range. Wood finishes and consumer products fell in the $10^4 - 10^5$ $\mu g/m^2$-hr range. Wood finishes are used only periodically and should have little long term effect regarding over-all indoor air quality. Consumer products, due to their continual use, may be one of the single largest determining factors regarding indoor air quality on a daily basis.

Since emission rates were based on chamber tests, no resulting indoor concentrations from consumer product use were published. If one assumes an entire floor being waxed, however, and a target TVOC concentration of 300 $\mu g/m^3$ the required ventilation rate would be 132 l/s-p (265 cfm/p). A target TVOC concentration of 3,000 $\mu g/m^3$ would require a ventilation rate of 13.2 l/s-p (26.5 cfm/p). The AVR would predict an indoor TVOC concentration of approximately 4,000 $\mu g/m^3$ at a ventilation rate of 10 l/s-p. This is demonstrated in Appendix A.

Many of the proposed revisions in Std. 62 appear to be an emphasis on source control and emission inventory to provide acceptable indoor air quality. The AVR appears to rely on building generated sources to predict necessary ventilation rates. Data summarized above indicate that this is not a constructive route to pursue. Other data, taken from real environments tends to support this. Grot et al. (1990) report that TVOC levels in buildings tend to parallel occupancy patterns, suggesting that most TVOC are occupant generated. They also demonstrate that TVOC levels will fall quite rapidly with increased ventilation (up to approximately 1 air change per hour). Holcomb and Seabrook (1994) have also reported significant declines in TVOC with increased ventilation. Holcomb (1993) reviews studies which demonstrate TVOC reductions both with time in a new building and with increased ventilation. Ekbert (1991) and Worthan (1993) report significant drops over a three month period in indoor levels of VOC and particulates in

newly constructed buildings. Ekbert (1991) also reported significant drops in formaldehyde concentrations.

Sundell (1994) reports that building related symptoms do not show an association with TVOC levels but do show an association with ventilation rates, particularly when the ventilation rates are quantified on a "per person" basis. The above observations all suggest that providing adequate ventilation, based on occupancy, are likely to provide acceptable indoor air quality while extensive concern over source inventories or source control may not be appropriate.

It should be recognized that especially high concentrations of many materials may be present during building renovation and in a new building, directly upon completion. Special precautions in ventilation and a time delay for occupancy during commissioning will prevent concentrations that exceed recognized standards.

Summary

A large body of data regarding emission rates is available. At this point, however, it is not suitable for use in projecting potential indoor air concentrations and required ventilation rates. Reasons for this are as follows:

1. Testing of emissions is done in chambers. The behavior of substances in chambers can be markedly different from that in real

life situations. This may be due primarily to the presence of sinks in real-world environments and the fact that whole building ventilation systems behave much differently than those in test chambers.

2. Emission testing protocols are not standardized. Materials can be tested new or aged. Chamber designs differ markedly. The choice of compounds to be measured can vary widely.

3. Measured emission rates can vary by over three orders of magnitude for a given substance emitted from a given product. Choosing a representative value from this range is difficult.

4. Recent changes in product formulation are changing both the quantitative and qualitative nature of emissions. The research on emission rates is not likely to keep up with market changes.

5. While there appears to be a substantial amount of data available, the amount of data for any given product is often not sufficient to determine if the data are representative. In addition, the number of potential emitting products in a given environment virtually precludes any attempt at a comprehensive source inventory.

6. The only substances for which much data exists are TVOC and formaldehyde. Given the number of potential substances in a given

environment and the uncertainty regarding cause and effect exposure relationships in indoor air, this is not much evidence from which to design ventilation systems.

7. Formaldehyde and TVOC emissions appear to be dependent on indoor concentrations, ventilation rates and loading factors. It may not be possible to estimate indoor concentrations based on literature emission rates and predict the effects of increased ventilation.

8. Consumer products such as waxes, cleaning products and deodorizers, have the greatest potential to impact indoor air quality due to TVOC emissions. Their initial emission rate can be very high (up to 10^8 $\mu g/m^2$-hr). They are often applied over fairly large areas. They can be used frequently. Based on this, attempting to predict concentrations due to carpets, wall covering, etc., may be missing the largest potential sources of emissions.

Conclusions

1. Current data do not allow prediction of indoor concentrations or required ventilation rates based on chamber tests of emission rates.

2. Data suggest rapid decreases in emission rates with product aging. This is enhanced by increased ventilation rates. A "flush

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out" with increased ventilation rates and a short delay in occupancy as part of building commissioning appears to be the best available strategy for controlling indoor concentrations.

3. Consumer products (i.e., waxes, cleaning products, deodorizers) appear to be the largest single (or combined) source of TVOC in indoor air. Due to the magnitude of their emissions, proper use of consumer products in a building may be one of the most significant strategies in controlling concentrations from a source control standpoint.

4. Proposed ASHRAE Std. 62 Table C-1a needs to be revised to reflect concentrations of materials that are backed up by recognized national authorities.

5. The proposed Alternate Ventialtion Rate procedure is meaningless in terms of predicting real-world IAQ concentrations of materials in indoor air.

References

Baechler, M.C. et al. 1989. Assessing Indoor Exposure to Volatile Organic Compounds Released from Paint Using the NASA Data Base. Presented at the 82nd Annual AWMA Meeting and Exhibition. June 25-30, 1989.

Ekberg, L.E. 1991. Indoor Air Quality in a New Office Building. IAQ '91: Healthy Buildings. pp. 125-127.

Holcomb, L.C. 1993. VOCs Reported in Indoor Air Indicate Potential for Avoiding Health and Irritation Problems. Presented at 86th Annual AWMA Meeting and Exhibition, Denver CO. June 13-18, 1994.

Holcomb, L.C. and Seabrook B.S. 1994. Indoor VOC Concentrations: What is Reasonably Achievable? IAQ Journal. May:25-27.

Grot, R.A. et al. 1990. Indoor Air Quality Evaluation of a New Office Building. Proceedings of the Fifth International Conference on Indoor Air Quality and Climate. Toronto, Canada. Inglewood Printing Plus, Aurora, ON. pp. 401-406.

Sundell, J. 1994. On the Association Between Building Ventilation Characteristics, some Indoor Environmental Exposures, some Allergic Manifestations and Subjective Symptom Reports. Indoor Air. Suppl. 2:1-49.

Worthan, T. 1993. A Pre-occupancy Indoor Air Investigation of a Newly Constructed Building. Presented at the American Industrial Hygiene Conference and Exposition '93. May 15-21, 1993.

TABLE 1. SUMMARY OF LITERATURE SOURCE STRENGTHS

1. Lofroth, G., et al. (1989) Characterization of environmental tobacco smoke. Environ. Sci. Technol. 23:610-614.

substance	μg/cig
CO	67 mg
NOx	1950 μg
RSP	10 mg
nicotine	800-3300 μg
formaldehyde	2 mg
acetaldehyde	2.4 mg
acrolein	0.56 mg
benzene	0.5 mg

Chamber studies with sidestream smoke

2. Mathews, T.G., et al. (1987) Interlaboratory comparison of formaldehyde emissions from particle board underlayment in small-scale environmental chambers. JAPCA. 37:1320-1326.

Formaldehyde - 154 $\mu g/m^2$-hr (79-240)

Interlab comparisons. Particleboard ≈ 1 year old. Formaldehyde emissions depend on formaldehyde concentration, product loading and ventilation parameters.

3. Tichenor, B. and Mason, M.A. (1988) Organic emissions from consumer products and building materials to the indoor environment. JAPCA. 38:264-268.

Particleboard - aged 8 months
formaldehyde - 155 $\mu g/m^2$-hr (95-230)
acetone - 38 $\mu g/m^2$-hr (37-41)

Floor adhesive - dried and/or at equilibrium
TVOC - 216 mg/m^2-hr

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Silicone caulk - brought to equilibrium
TVOC - 26 mg/m^2-hr

Graphs show significant drops in emissions and concentrations with time. Tables give several examples of organic compounds in products.

4. Knoppel, H. and Schauenburg, H. (1989) Screening of household products for the emissions of volatile organic compounds. Environment International. 15:413-418.

TVOC

paste wax	430 $\mu g/cm^2$-min.	liquid wax	0.5 $\mu g/cm^2$-min.
liquid wax	160 "	detergent	0.4 "
paste wax	5.5 "	liquid wax	0.3 "
detergent	1.8 "	liquid wax	0.3 "
liquid wax	0.8 "	liquid wax	0.2 "

Waxes are several different applications (furniture, floor, etc.). Products are measured as applied.

5. Tichenor, B. (1989) Measurement of organic compound emissions using small test chambers. Environment International. 15:389-396.

	para-dichlorobenzene
Moth crystals	1,530 $\mu g/cm^2$-hr. @ 23°C
	4,963 $\mu g/cm^2$-hr. @ 35°C

Emission rate increases with ventilation rate. Graphs show dramatic decreases in emission rates and concentrations with time. Higher air exchange rates results in more rapid depletion of source. Individual compounds can show markedly different emission rates.

6. Bayer, C.W. (1990) An investigation into the effect of building bake-out conditions on building materials and furnishings. Indoor Air '90. 3:581-586.

TVOC Emissions in $\mu g/m^2$-hr.

Product	Average Before	Average After
Partitions	23.9	37.5
Particleboard 1	737	547
Particleboard 2	10.8	24.7

PARTICLEBOARD 1

Compound	Pre 1	Pre 2	Post 1	Post 2	
Methylene Chloride	19.0	100	23.9	0.9	($\mu g/m^2$-hr.)
Benzene	386	57.7	1,480	29.4	
Toluene	1,121	37.9	408	866	
Acetone	0.75	3.13	ND	0.566	

PARTICLEBOARD 2

Compound	Pre	Post 1	Post 2	
Methylene Chloride	0.12	3.83	1.86	($\mu g/m^2$-hr)
Benzene	0.24	13.9	1.69	
Toluene	ND	13.9	1.69	

Simulated bake-out in a test chamber.

7. Gschwandtner, G. et al. (1989) Measurements of indoor particulate pollution from household vacuum cleaning. 82nd Annual AWMA Meeting & Exhibition, Anaheim, CA. June 25-30, 1989.

TPM - 2,507 $\mu g/m^3$ - 30 minutes of vacuuming

Test run in test room w/carpet using prepared "test dirt".

8. Viner, A.S. et al. (1989) Ozone emissions from air cleaners. 82nd Annual AWMA Meeting & Exhibition, Anaheim, CA. June 25-30, 1989.

O_3 generation rates - $\approx 5\ \mu g/s$ - $20.4\ \mu g/s$

9. Colombo, A. et al. (1990) Determination of volatile organic compounds emitted from household products in small test chambers and comparison with headspace analysis. Indoor Air '90. 3:599-604.

Product	Emitting surface area	Initial TVOC emission rate (mg/hr)
liquid cleanser	328 cm^2	34.9
liquid floor detergent	1312	2.2
carpet spray cleaner	462	50.4
furniture polish spray	900	27.1
floor paste wax	328	1.88

Tests run in small test chambers. Some individual VOC are provided; common VOC which are given:

product 1 - camphor	1.19 mg/hr
product 2 - formaldehyde	2.89 mg/hr
product 5 - α-pinene	0.641 mg/hr

10. Engstram, K. (1990) Building materials; A source of indoor air pollution. Indoor Air '90. 3:677-681.

277 materials tested in small (0.06 m^3) chamber: 43 floor coverings, 59 wall coverings, 55 insulation materials, 45 textiles, 19 paints, eight other furnishing materials. Quantity of substance tested adjusted to represent loading factors (m^2/m^3) found in rooms. Material aged three months prior to testing.

		Emission rate (μg/hr)	
compound	N	median	range
formaldehyde	99	0.21	0.046 - 9.89
phenol	48	0.086	0.034 - 2.71
freon	15	1.9	0.12 - 21.1
xylene	14	0.22	0.033 - 5.61
MIBK	13	0.16	0.040 - 7.19
heptachlor	12	0.013	0.0004 -1.46
butylalcohol	11	0.099	0.066 - 3.96
cyclohexanone	11	0.44	0.15 - 41.1

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ethylbenzene	11	0.066	0.013 - 1.12
acetone	10	0.99	0.26 - 2.38
aliphatic hydrocarbons	10	0.66	0.056 - 4.29
toluene	10	0.21	0.099 - 28.9

Comments: Emissions/surface area of material are not given. Given the chamber volume ($0.06m^3$) and loading factors ($0.5 - 1.5\ m^2/m^3$) they are expected to be 8-25 times the presented values if expressed as $\mu g/m^2$-hr. This is the largest selection of tested materials found to date. The fact that they are slightly aged adds to their usefulness. However, the fact that the emission rate range typically spans 2 - 3 orders of magnitude limits their usefulness in practical applications.

11. Person, A. (1990) Characterization of volatile organic compounds emitted by liquid and pasty household products via small test chamber. Indoor Air '90. 3:605-610.

Product	TVOC emissions ($\mu g/cm^2$-hr)
solvent based glues	507 -1650
water based glues	$\leq$1 - 210
floor cleaning products	1 - 14
deodorizers	20 - 210
waxes	$\leq$1 - 9

Graph shows concentrations in chamber dropping with time for water based glue. Products appear to be tested fresh.

12. van der Wal, J.F. (1990) Measurement of organic compound emissions from consumer products in a walk-in test chamber. Indoor Air '90. 3:611-616.

Product/compound	Emission rate ($\mu g/m^2$-hr)	
	1 -2 hrs.	24 hrs
Vinyl floor covering		
formaldehyde		30
toluene	70	60 - 70
xylenes	625	240
N-alkanes	9700	3900
iso-alkanes	28,000	11,250

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Vinyl coated wallpaper		
toluene	10	5-50
chlorinated hydrocarbons	10	10-20
formaldehyde		15
Plywood		
formaldehyde	15 - 1060	5 - 720
terpenes	300 - 2400	80 - 850
Polystyrene foam		
styrene	500 - 740	5 -180
ethylbenzene	160 - 190	15 - 55

Products were tested new.

13. Bluyssen, P.M. and Fanger, O. (1991) Addition of olfs from different pollution sources, determined by a trained panel. Indoor Air. 4:414-421.

Material	Source Strengths (Olfs)
carpet	0.90
rubber doormat	1.28
sealant	0.87
paint	0.24
linoleum	0.34
filter	0.34
heat exchanger material	0.91
humidifier paper	0.59
galvanized steel	0.14
newspapers	0.56
cigarette butts	1.46

All materials (except newspapers and cigarette butts) were stated to have been stored in closed jars for about one year. The quantity of material tested is unknown. A table of source combinations is given. Source strengths appear to be additive.

14. Wallace, L.A., et al. (1987) Emission rates of volatile organic compounds from building materials and surface coatings. Proc. 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants.

Product	Emissions ($\mu g/m^2$-hr)		
	Aromatic	Aliphatic	Chlorinated
vinyl molding	20.1	66.9	2.33
rubber molding	35.88	54.1	1.39
polystyrene insulation	26.64	----	1.05
linoleum	17.24	1.65	1.3
carpet	0.92	13.73	----
particleboard	1.4	6.8	0.18
cove adhesive	1,934	----	----
carpet adhesive	2,292	5,540	----
latex paint	290.8	720	290.9

Products aged $\leq$ 4 months. Liquid products are believed to have been tested wet. A building constructed of these materials was monitored to compare with modeled results. Monitoring results are stated to compare favorably with modeled results.

15. Hodgson, A.T., et al. (1993) Emissions of volatile organic compounds from new carpets measured in a large scale environmental chamber. J. Air and Waste Management Association. 43:316-324.

Carpet	Emissions ($\mu g/m^2$-hr) ($\pm$ 95% C.I.)	
	24 hr	168 hr
1a. 4-PCH	85.1 ± 2.3	64.0 ± 2.5
TVOC	213 ± 9.6	71.2 ± 9.9
1b. 4-PCH	64.5 ± 3.1	48.5 ± 2.4
TVOC	178 ± 15.9	51.2 ± 15.0
2. TVOC	83.3 ± 25.0	32.5 ± 12.5
3. formaldehyde	57.2	18.2
TVOC	602 ± 23.5	192 ± 48.4
4. TVOC	399	93.9 ± 14.1

16. Silberstein, S., et al. (1988) Validation of models for predicting formaldehyde concentrations in residences due to pressed-wood products. JAPCA. 38:1403-1411.

Product	Formaldehyde Emission (mg/m^2-hr)
particleboard	0.09 - 0.18
plywood paneling	0.005 - 0.11
fiberboard table tops	1.21 - 1.30

Article discusses models for predicting indoor concentrations. Formaldehyde emissions negatively correlated with concentrations.

17. Hayes, S.R. (1991) Use of an indoor air quality model (IAQM) to estimate indoor ozone levels. J. Air and Waste Management Assoc. 41:161-170.

Indoor:Outdoor O_3 ratios
- Homes - 0.10-0.70
- Offices - 0.19-0.80
- 100% outdoor air - 0.82
- 34% OA (typical) - 0.60
- 10% OA (energy efficient) - 0.32

No discussion of indoor sources.

18. Tichenor, B.A., et al. (1990) Evaluating sources of indoor air pollution. J. Air and Waste Management Assoc. 40:487-492.

Moth Crystal Cakes	
p-dichlorobenzene	1.4 mg/cm^2-hr
Kerosene Heaters	
particulates	38-376 μg/g fuel burned

P-dichlorobenzene and TVOC emissions increased with both temperature and ventilation rates. Individual compounds can show markedly different emission rates.

19. Holcomb, L.C. and Pedelty, J.F. (1991) The impact of ventilation on indoor air quality: environmental tobacco smoke as a point source. 84th Annual AWMA Meeting & Exhibition, British Columbia, June 16-21, 1991.

ETS given 20% smokers and 1 cigarette/hr

Substance	$\mu g/m^3$-hr	ppb/hr
CO	272	234
NH_3	38	54
formaldehyde	4.4	3.5
NOx	9.4	8.0
RSP	42.4	---
Alkanes	---	0.5
Benzene	0.9	0.3
SO_2	---	1.0
Nicotine	25.0	3.8
B(a)P	0.44 ng/m^3-hr	

20. Sparks, L.E., et al. (1991) Comparison of data from an IAQ test house with predictions of an IAQ model. Indoor Air. 4:577-592.

Substance	Initial Emission Rate (TVOC)	Application Emission Rate
wood stain	20,000 mg/m^2-hr	1,000 mg/m^2-hr
polyurethane	20,000	1,000
wood floor wax	20,000	1,000
moth cakes	14,000	
dry cleaned clothing	1.4	

Graphs show dramatic drop in indoor concentrations with time.

21. Brown, S.K., et al. (1994) Concentrations of volatile organics in indoor air: A review. Indoor Air. 4:123-134.

Source description	Emission rate (μg/m²·h)	Reference
Household products ("wet")		
1. solvent-based waxes/detergents	up to 2.6×10^8	Knoppel & Schauenberg (1987)
2. waxes spread on surfaces	$1.0 \times 10^6 - 9.4 \times 10^7$	
3. toilet deodorisers	$1.3 \times 10^6 - 3.7 \times 10^6$	Person et al. (1990)
4. room deodorisers	$1.6 \times 10^5 - 2.0 \times 10^6$	
5. liquid cleaner/disinfectant	1.1×10^6	Colombo et al. (1990)
6. carpet spray cleaner	1.1×10^6	
7. water-based waxes/detergents	$1.2 \times 10^5 - 1.2 \times 10^6$	Knoppel & Schauenberg (1987)
8. furniture spray polish	3.0×10^5	Colombo et al. (1990)
9. floor cleaners	$< 10^4 - 1.5 \times 10^5$	Person et al. (1990)
10. floor wax paste	6.0×10^4	Colombo et al. (1990)
11. dry cleaned clothing	2.7×10^4	Sparks et al. (1990)
12. floor wax	2.0×10^4	Sparks et al. (1990)
13. liquid floor detergent	1.7×10^4	Colombo et al. (1990)
Construction products ("wet")		
1. solvent-based adhesives	$5.1 \times 10^6 - 1.7 \times 10^7$	Person et al. (1990)
2. water-based adhesives	$< 10^4 - 2.1 \times 10^6$	Person et al. (1990)
3. wall/flooring glue (EVA)	2.7×10^5	Mølhave (1982)
4. sealants (incl. silicones)	$300 - 7.2 \times 10^4$	Mølhave (1982)
5. wood stain	1.7×10^4	Sparks et al. (1990)
6. polyurethane lacquer	6×10^3	Sparks et al. (1990)
7. floor varnishes (3 types)	$830 - 4.7 \times 10^3$	Mølhave (1982)
8. PVA glue (water-based)	2.1×10^3	Mølhave (1982)
Construction products ("dry")		
1. new vinyl flooring	$1.9 \times 10^4 - 4.3 \times 10^4$	Van der Wal et al. (1990)
	$120 - 2.3 \times 10^3$	Mølhave (1982)
2. rubber floor covering	1.4×10^3	Mølhave (1982)
	410	Wolkoff et al. (1990)
3. plywoods	$300 - 2.4 \times 10^3$	Van der Wal et al. (1990)
4. polystyrene foam	40	Mølhave (1982)
	1.4×10^3	Mølhave (1982)
	$30 - 10^3$	Van der Wal et al. (1990)
5. textile floor covering	$.80 - 1.6 \times 10^3$	Mølhave (1982)
6. plastic floor covering	220 – 590	Mølhave (1982)
7. rubber-backed nylon carpet	300	Wolkoff et al. (1990)
	50 – 180	Black (1990)
8. felt-carpet	80 – 110	Mølhave (1982)
9. painted gypsumboard/particleboard	240 – 260	Wolkoff et al. (1990)
10. particleboard, fibreboard	120 – 140	Mølhave (1982)
11. polyurethane foam	120	Mølhave (1982)
12. wallpapers (incl. vinyl)	30 – 300	Mølhave (1982)
13. gypsumboard	30	Mølhave (1982)
14. GRP sheeting	20	Mølhave (1982)
15. mineral wool	10	Mølhave (1982)

22. Groah, W.J., et al. (1994)? Formaldehyde release and home concentration projections from low-emitting hardwood plywood wall paneling and particleboard materials.

Substance	Emission Rate (mg/m^2-hr)
hardwood plywood wall paneling	0.01 - 0.194
particleboard	0.019 - 0.35

Emission rate appears to be primarily determined by ventilation rate and loading. Equation $ER=1.23\ C_S \times N/L$ is given where:

ER = Emission Rate (mg/m^2-hr)
C_S = formaldehyde concentration @ steady state (ppm)
N = ventilation rate (ACH)
L = loading (m^2/m^3)

23. Sundin, E.B., et al. (1992) Emission of formaldehyde and other volatile organic compounds from sawdust and lumber, different wood-based panels, and other building materials: A comparative study. Proceedings 26th Wash. State Univ. International Particleboard/Composite Materials Symposium. Pullman, WA. April 7-9, 1992.

Product	TVOC (mg/m^2-hr)	Formaldehyde (mg/m^2-hr)
hardboard	0.03	0.03
plywood	0.05	0.03
gypsumboard	0.05	0.03
lumber, pine	0.31	0.03
particleboard, 2 wks	0.15	0.05
particleboard, 10 yrs	0.04	0.13
other particleboards	0.02 - 0.04	-

24. Black, M.S., et al. (1993) Measuring the TVOC contributions of carpet using environmental chambers. Indoor Air '93. 2:401-405.

Product	TVOC emissions (mg/m^2-hr)	Primary VOC
carpet 1 (SBR)*	0.35 - 0.48	styrene, 4-PC
carpet 2 (non-SBR)*	0.68 - 0.70	trimethyl pentane, acetic acid

*SBR - styrene butadiene rubber

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Product	TVOC emissions (mg/m^2-hr)		
	Day 0	Day 1	Day 6
carpet only	62	35	6
adhesive only	2770	2350	13
installed carpet (no seam)	414	2020	111
seam sealant only	2960	249	10

25. DeBortoli, M., et al. (1993) Emission of formaldehyde, vinyl chloride, VOC's and plasticizer from different wallcoating materials. Indoor Air '93. 2:413 - 418.

Product	(mg/m^2-hr) TVOC		Formaldehyde		Time
	peak	end	peak	end	(hr)
wallpaper	0.67	0.032	0.56	0.019	24
duplex wallpaper	0.09	0.030	0.20	0.019	71
surface printing w.p.	0.24	0.07	0.27	0.025	23
blown vinyl	0.44	0.007	0.015	0.004	32
expanded vinyl	1.78	0.021	0.012	0.003	144
flat vinyl	24.43	0.21	0.037	0.005	95
prepasted vinyl	1.37	0.37	0.012	0.003	23
cotton backed vinyl	48.8	5.08	0.004	ND	71

26. Bremer, J., et al. (1993) Measurement and characterization of emissions from PVC materials for indoor use. Indoor Air '93. 2:419-424.

Dynamic modeling of VOC emissions from PVC flooring. Approx 150 compounds identified. Source strengths not given.

27. Gehrig, R., et al. (1993) VOC emissions from wall paints - A test chamber study. Indoor Air '93. 2:431-436.

Source strengths not given (vent. rate = 1 ACH, painted area = 0.25 m^2, loading ratio = 0.17 m^2/m^3) Paint spread in three support materials. TVOC chamber concentrations peaked at $\approx$37 - 45 mg/m^3 in $\approx$0.5 - 0.75 hr. Concentrations were $\approx$1 mg/m^3 within 27-30 hrs.

28. Gustafsson, H. and Jenssen, B. (1993) Trade standards for testing chemical emissions from building materials. Part 1 measurements of flooring materials.

35 different flooring samples

4 weeks conditioning	TVOC emissions	average 372	$\approx$50-1400 $\mu g/m^2$-hr
26 weeks conditioning	TVOC emissions	average 115	$\approx$25- 800 $\mu g/m^2$-hr

29. Tirkkonen, T., et al. (1993) Volatile organic compound emission from some building and furnishing material. Indoor Air '93. 2:477-482.

Product	TVOC emissions ($\mu g/m^2$-hr)
gypsumboard, new	3
mineral wool, new	106
glass wool, new	131
cellulose wool, new	777
expanded polystyrene, new	177
paints, 2 week old	10-3833
wallpaper, new	23
vinyl flooring, new	889-4898
PVC flooring, new	162-261
Cl-free floor tile, new	36

30. Saarela, K. and Sendell, E. (1991) Comparative emission studies of flooring materials with reference to Nordic Guidelines. IAQ '91, Healthy Buildings. pp 262-266.

Product	TVOC emissions (mg/m^2-hr)
soft woods (pine, birch), new	0.157-0.682
linoleum, old	0.064
cork	0.007-0.805
PVC flooring*	0.273-7.034

*age is not reflected in emission rates

31. Koutrakis, P., et al. (1991) Source Apportionment of Indoor Aerosols in Suffolk and Onendega Counties, New York. Submitted to Env. Sci. Technol. (Published?)

ETS particulates 12,657 μg/cig

Based on monitoring and modeling in homes. Metal emissions are given for smoking, wood stoves and kerosene heaters but none which appear toxicologically significant.

32. Lofroth, G., et al. (1987) Genotoxic emission factors for sidestream smoke. EMS Abstracts. pg 61

Sidestream smoke
- CO - 60 mg/cig.
- NOx - 2 mg/cig (primarily NO)
- TVOC - 30 mg/cig
- nicotine- 0.7 mg/cig
- particulates - 8 mg/cig

based on chamber studies

Footnotes:

All emission rates reported in this table are listed in the same units which they were given in the publication. No conversions to other units have been performed.

TABLE 2. EMISSION RATES BY PRODUCT CATEGORY

ETS

CO	67 mg/cig	272 $\mu g/m^3$-hr	46 mg/cig
NOx	1950 μg/cig	9.4 $\mu g/m^3$-hr	1598 μg/cig
RSP	10 mg/cig	42.4 $\mu g/m^3$-hr	7.2 mg/cig
Nicotine	800-3300 μg/cig	25 $\mu g/m^3$-hr	4.25 mg/cig
Formaldehyde	2 mg/cig	4.4 $\mu g/m^3$-hr	748 μg/cig
Benzene	0.5 mg/cig	0.9 $\mu g/m^3$-hr	153 μg/cig
Reference	(1)	(19)	(19, in μg/cig)

CO	60 mg/cig	
NOx	2 mg/cig	
RSP	8 mg/cig	12,657 μg/cig
Nicotine	0.7 mg/cig	
TVOC	30 mg/cig	
Reference	(32)	(31)

ETS Summary

CO	46-67 mg/cig
NOx	1600-2000 μg/cig
RSP	7.2 - 12.7 mg/cig
Nicotine	0.7-4.25 mg/cig
Formaldehyde	0.7-2 mg/cig
Benzene	0.2-0.5 mg/cig
TVOC	30 mg/cig

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Wall Coverings

Ref #	Material	Emission	Emission Rate
(12)	Wallpaper	formaldehyde	15 $\mu g/m^2$-hr
(25)	Wallpaper	formaldehyde	0.003-0.025 mg/m^2-hr (aged values)
		TVOC	0.007-5.08 mg/m^2-hr (aged values)
(29)	Wallpaper	TVOC	23 $\mu g/m^2$-hr
(21)	Wallpaper	TVOC	30-300 $\mu g/m^2$-hr
(14)	Latex paint	TVOC	1301.7 $\mu g/m^2$-hr
(29)	Paint	TVOC	10-3833 $\mu g/m^2$-hr
(22)	Plywood paneling	formaldehyde	0.01-0.194 mg/m^2-hr
(16)	Plywood paneling	formaldehyde	0.005-0.11 mg/m^2-hr

Wall Covering Summary

Wallpaper	TVOC	7-5,080 $\mu g/m^2$-hr
	formaldehyde	3-25 $\mu g/m^2$-hr
Paint	TVOC	10-3833 $\mu g/m^2$-hr
Paneling	formaldehyde	5-194 $\mu g/m^2$-hr

Floor Coverings

Ref #	Material	Emission	Emission Rate
(12)	vinyl	formaldehyde	30 $\mu g/m^2$-hr
		TVOC	15,460 $\mu g/m^2$-hr (24 hrs.)
(14)	linoleum	TVOC	20.19 $\mu g/m^2$-hr
(28)	flooring samples	TVOC	25-1400 $\mu g/m^2$-hr (avg. 4-26 wks ageing)
(29)	vinyl/PVC	TVOC	162-4898 $\mu g/m^2$-hr (new)
(30)	linoleum/PVC	TVOC	0.064-7.034 mg/m^2-hr
(21)	vinyl/rubber	TVOC	120-4.3x10^4 $\mu g/m^2$-hr
(14)	carpet	TVOC	14.65 $\mu g/m^2$-hr
(15)	carpets	TVOC	32.5-192 $\mu g/m^2$-hr (one week ageing)
		formaldehyde	18.2 $\mu g/m^2$-hr (one week ageing)
		4-PCH	48.5-64 $\mu g/m^2$-hr (one week ageing)
(21)	textile/carpet	TVOC	50-1600 $\mu g/m^2$-hr
(24)	carpet	TVOC	111-2020 $\mu g/m^2$-hr (24 hr - 1 week ageing)

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Floor Covering Summary

vinyl/linoleum	TVOC	20.19-15,460 $\mu g/m^2$-hr
	formaldehyde	30 $\mu g/m^2$-hr
Carpet	TVOC	14.65-2020 $\mu g/m^2$-hr
	formaldehyde	18.2 $\mu g/m^2$-hr
	4-PCH	48.5-64 $\mu g/m^2$-hr

Building Materials

Ref #	Material	Emission	Emission Rate
(2)	particleboard	formaldehyde	154 $\mu g/m^2$-hr
(3)	particleboard	formaldehyde	155 $\mu g/m^2$-hr
(6)	particleboard	TVOC	24.7-547 $\mu g/m^2$-hr (after simulated bakeout)
(14)	particleboard	TVOC	8.38 $\mu g/m^2$-hr
(16)	particleboard	formaldehyde	0.09-0.18 mg/m^2-hr
(21)	gypsumboard/particleboard	TVOC	30-260 $\mu g/m^2$-hr
(22)	particleboard	formaldehyde	0.019-0.35 mg/m^2-hr
(23)	gypsumboard	TVOC	0.05 mg/m^2-hr
		formaldehyde	0.03 mg/m^2-hr
	particleboard	TVOC	0.02-0.15 mg/m^2-hr
		formaldehyde	0.05-0.13 mg/m^2-hr
(29)	gypsumboard	TVOC	3.0 $\mu g/m^2$-hr
(12)	plywood	formaldehyde	5.0-720 $\mu g/m^2$-hr
(23)	plywood	TVOC	0.05 mg/m^2-hr
		formaldehyde	0.03 mg/m^2-hr
(21)	plywood	TVOC	300-2,400 $\mu g/m^2$-hr
(23)	hardboard/pine	TVOC	0.03-0.31 mg/m^2-hr
		formaldehyde	0.03 mg/m^2-hr
(30)	pine/birch	TVOC	0.157-0.682 mg/m^2-hr (new)
(20)	wood stain	TVOC	1,000 mg/m^2-hr (as applied)
	polyurethane	TVOC	1,000 mg/m^2-hr (as applied)
(21)	wood stain	TVOC	1.7×10^4 $\mu g/m^2$-hr
	polyurethane	TVOC	6.0×10^3 $\mu g/m^2$-hr
(3)	floor adhesive	TVOC	216 mg/m^2-hr (dried/equilibrium)
(11)	water based glues	TVOC	< 1-210 $\mu g/cm^2$-hr

	solvent based glues	TVOC	507-1,650 $\mu g/cm^2$-hr
(14)	cove adhesive	TVOC	1,934 $\mu g/m^2$-hr
	carpet adhesive	TVOC	7,832 $\mu g/m^2$-hr
(24)	carpet adhesive	TVOC	13 $\mu g/m^2$-hr (day 6); 2,350 (day 1)
(21)	solvent based adhesive	TVOC	$5.1x10^6$-$1.7x10^7$ $\mu g/m^2$-hr
	water based adhesive	TVOC	$< 10^4$-$2.1x10^6$ $\mu g/m^2$-hr
	wall/flooring glue	TVOC	$2.7x10^5$ $\mu g/m^2$-hr
	PVA glue (water based)	TVOC	$2.1x10^3$ $\mu g/m^2$-hr
(14)	polystyrene insulation	TVOC	27.69 $\mu g/m^2$-hr
(29)	mineral/glass wool	TVOC	106-131 $\mu g/m^2$-hr
	cellulose wool	TVOC	777 $\mu g/m^2$-hr
	extruded polystyrene	TVOC	177 $\mu g/m^2$-hr
(21)	polystyrene foam	TVOC	30-$1.4x10^3$ $\mu g/m^2$-hr
	polyurethane foam	TVOC	120 $\mu g/m^2$-hr

<u>Building Material Summary</u>

particleboard	TVOC	8.38-547 $\mu g/m^2$-hr
	formaldehyde	19-350 $\mu g/m^2$-hr
gypsumboard	TVOC	3-50 $\mu g/m^2$-hr
	formaldehyde	30 $\mu g/m^2$-hr
plywood	TVOC	50-2400 $\mu g/m^2$-hr
	formaldehyde	5-720 $\mu g/m^2$-hr
lumber (pine/birch)	TVOC	30-682 $\mu g/m^2$-hr
wood stain	TVOC	17,000-10^6 $\mu g/m^2$-hr
polyurethane	TVOC	6,000-10^6 $\mu g/m^2$-hr
solvent base adhesive	TVOC	13-$1.7x10^7$ $\mu g/m^2$-hr
water base adhesive	TVOC	$\leq$ 1-$2.1x10^6$ $\mu g/m^2$-hr
polystyrene/polyurethane insulation	TVOC	27.69-1,400 $\mu g/m^2$-hr
mineral/glass wool	TVOC	106-131 $\mu g/m^2$-hr
cellulose wool	TVOC	777 $\mu g/m^2$-hr

Consumer Products

Ref #	Material	Emission	Emission Rate
(4)	wax	TVOC	2,000-4.3x10^6 $\mu g/m^2$-hr
(9)	furniture polish	TVOC	3.01x10^5 $\mu g/m^2$-hr
	wax	TVOC	5.7x10^4 $\mu g/m^2$-hr
(11)	waxes	TVOC	$\leq$10,000-90,000 $\mu g/m^2$-hr
(4)	detergent	TVOC	4,000-18,000 $\mu g/m^2$-hr
(9)	detergent/cleanser	TVOC	16,768-1.1x10^6 $\mu g/m^2$-hr
(11)	floor cleaning products	TVOC	10,000-140,000 $\mu g/m^2$-hr
(21)	waxes/detergents	TVOC	1.7x10^4-2.6x10^8 $\mu g/m^2$-hr
(5)	moth crystals	TVOC	1.53x10^7-4.963x10^7 $\mu g/m^2$-hr
(18)	moth cakes	p. dichlorobenzene	1.4x10^7 $\mu g/m^2$-hr
(20)	moth cakes	p. dichlorobenzene	1.4x10^7 $\mu g/m^2$-hr
(21)	room/toilet deodorizer	TVOC	1.6x10^5-3.7x10^6 $\mu g/m^2$-hr
(11)	deodorizers	TVOC	2x10^5-2.1x10^6 $\mu g/m^2$-hr

Consumer Product Summary

waxes	TVOC	2x10^3-2.6x10^8 $\mu g/m^2$-hr
detergents	TVOC	4x10^3-2.6x10^8 $\mu g/m^2$-hr
deodorizers	TVOC	1.6x10^5-3.7x10^6 $\mu g/m^2$-hr
moth crystals	TVOC	1.4x10^7-4.963x10^7 $\mu g/m^2$-hr

Miscellaneous

Ref #	Material	Emission	Emission Rate
(7)	vacuum cleaning	TPM	5,014 $\mu g/m^3$-hr
(8)	air cleaners	ozone	$\approx$5-20.4 μg-s
(16)	fiberboard table tops	formaldehyde	1.21x10^3-1.3x10^3 $\mu g/m^2$-hr
(20)	dry cleaned clothing		1.4x10^3 $\mu g/m^2$-hr
(3)	caulking	TVOC	2.6x10^4 $\mu g/m^2$-hr

Footnotes:

Emission rates are all believed to be based on a "per unit area of sample" basis.

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TABLE 3. EMISSION RATES FROM LITERATURE SOURCES

Product	Emission	Emission Rate ($\mu g/m^2$-hr)	Range
Wallpaper	TVOC	500	7 - 5,080
	Formaldehyde	10	3 - 25
Paint	TVOC	200	10 - 3,833
Paneling	Formaldehyde	50	5 - 194
Vinyl/linoleum	TVOC	2,000	20.19 - 15,460
	Formaldehyde	30	30
Carpet	TVOC	200	14.65 - 2,020
	Formaldehyde	10	18.2
	4 - PCH	30	48.5 - 64
Particleboard	TVOC	50	8.38 - 547
	Formaldehyde	50	19 - 350
Gypsumboard	TVOC	10	3 - 50
	Formaldehyde	30	30
Plywood	TVOC	100	50 - 2,400
	Formaldehyde	50	5 - 720
Lumber	TVOC	100	30 - 682
Wood Stain	TVOC	20,000	1.7×10^4 - 1×10^6
Polyurethane	TVOC	10,000	6×10^3 - 1×10^6
Solvent-based Adhesive	TVOC	200	13 - 1.7×10^7
Water-based Adhesive	TVOC	50	<1 - 2.1×10^6
Insulation	TVOC	200	27.69 - 1.4×10^3

Waxes	TVOC	10,000	$2x10^3 - 2.6x10^8$
Detergents	TVOC	10,000	$4x10^3 - 2.6x10^8$
Deodorizers	TVOC	100,000	$1.6x10^5 - 3.7x10^6$
Moth Crystals	TVOC (p-dichlorobenzene)	15,000,000	$1.4x10^7 - 4.96x10^7$
ETS	Carbon Monoxide	0.75	0.64 - 0.94
	NOx	0.025	0.022 - 0.028
	RSP	0.12	0.10 - 0.18
	Nicotine	0.030	0.0098 - 0.060
	Formaldehyde	0.02	0.0098 - 0.028
	Benzene	0.005	0.0028 - 0.007
	TVOC	0.42	0.42

Footnotes:

All emission rates in this table are listed on a "per unit area of sample" basis.
Unit conversions have been performed to report all emission rates on a $\mu g/m^2$-hr basis.
Conversion factors for ETS from "per cigarette" to "per m^2-hr" can be found in Appendix B.

TABLE 4. EMISSION RATES FOR INDOOR SURFACES

Surface/Material	Emission	Rate	Range ($\mu g/m^2$-hr; floor space)
Walls			
wallpaper	TVOC	1,400	19.6 - 14,224
	formaldehyde	28	8.4 - 70
paint	TVOC	560	28 - 10,732.4
paneling	formaldehyde	140	14 - 543.2
gypsumboard	TVOC	84	84
	formaldehyde	140	140 - 364
insulation (1 wall, not UFFI)	TVOC	140	19.4 - 9,800
Floors			
vinyl/linoleum	TVOC	2,000	20.19 - 15,460
	formaldehyde	30	30
carpet	TVOC	200	14.65 - 2,020
	formaldehyde	10	18.2
	4-PCH	30	48.5 - 64
plywood	TVOC	100	50 - 2,400
	formaldehyde	50	5 - 720
adhesive, solvent based	TVOC	200	$13 - 1.7 \times 10^7$
adhesive, water based	TVOC	50	$<1 - 2.1 \times 10^6$
waxes	TVOC	10,000	$2 \times 10^3 - 2.6 \times 10^8$
detergents	TVOC	10,000	$4 \times 10^3 - 2.6 \times 10^8$

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Furniture			
particleboard	TVOC	65	10.9 - 711.1
	formaldehyde	65	24.7 - 455
waxes	TVOC	13,000	$2.6 \times 10^3 - 3.4 \times 10^8$
detergents	TVOC	13,000	$5.2 \times 10^3 - 3.4 \times 10^8$
ETS	CO	0.75	0.064 - 0.94
	NOx	0.025	0.022 - 0.028
	RSP	0.12	0.10 - 0.18
	nicotine	0.030	0.0098 - 0.06
	formaldehyde	0.02	0.0098 - 0.028
	benzene	0.005	0.0028 - 0.007
	TVOC	0.42	0.42

Footnotes:

Conversion from "per area of sample" to "per area of floor space" was performed using the assumptions at the end of Table H-1. These are listed in Appendix B.

Materials listed in Table 3 but not found here are due to the lack of conversion factors in Table H-1

TABLE 5. Holcomb Emission Rates Compared to Table H-1 Emission Rates

Substance	Emission	Table H-1 Value	Holcomb Value (published range)
Resilient Flooring	Formaldehyde	0.03 mg/m^2-hr	0.03 (0.03) mg/m^2-hr
	TVOC	2.0	2.0 (0.020 - 15.49)
Carpet	Formaldehyde	0.01	0.01 (0.018)
	TVOC	0.15	0.20 (0.015 - 1.6)
Wall Coverings	Formaldehyde	0.015	0.028 - 0.014 (0.003 - 0.56)
	TVOC	0.3	1.4 (0.020 - 14.2)
Painted Surfaces	Formaldehyde	0.4	---
	TVOC	0.3 - 20	0.56 (0.003 - 10.7)
Furniture	Formaldehyde	0.3	0.065 (0.004 - 0.711)
	TVOC	1.0	0.065 (0.025 - 0.455)
ETS	Carbon Monoxide	0.09	0.75 (0.064 - 0.94)
	Formaldehyde	1.0	0.02 (0.0098 - 0.028)
	NO_2	0.2	0.025 (0.022 - 0.028)
	Particulates	0.8	0.12 (0.10 - 0.18)
	TVOC	9.0	0.42 (0.42)

Footnotes:

Holcomb values do not include plywood or glue for flooring emissions or gypsum board for wall covering emissions.

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An example of AVR calculations - Assuming an office with resilient flooring, painted walls and typical furniture and using proposed draft Table H-1 ER values.

ER for HCHO = 0.03 + 0.4 + 0.3 = 0.73
ER for TVOC = 2 + 0.3 + 1 = 3.3

AVR = 278(ER/C) if Co and CRA = 0

For HCHO AVR = 278 (0.73/100) = 2.03 $l/s\text{-}m^2$
@ 7 $p/100\ m^2$ = **29 l/s-p (54 cfm/p)**

For TVOC AVR = 278 (3.3/300) = 3.06 $l/s\text{-}m^2$
@ 7 $p/100\ m^2$ = **43.7 l/s-p (87.4 cfm/p)**

This does not include any other volatile organic or formaldehyde sources either indoors or outdoors. Increases in the calculated AVR will occur either due to additional sources or incomplete mixing. This is also the "typical" indoor environment with no "strong" sources that is amenable to the MVR.

Calculating Indoor Air Concentrations - If the AVR equation is solved for C then typical values for ER and AVR can be plugged in to predict resulting indoor concentrations. This can be compared with actual indoor concentrations from the literature, providing a "reality check" for the AVR method.

AVR = 278(ER/C) assuming Co & CRA = 0

C = 278(ER/AVR)

If one further assumes AVR = 10 l/s-p or 0.7 l/m^2-p (@ 7 $p/100\ m^2$) then:
C = 397 X ER

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For smoking:

Substance	ER (Table H-1)	C ($\mu g/m^3$)	Real Levels in offices and public places due to ETS (Holcomb,1993)
CO	0.09	35.7	0 ppm
HCHO	1.0	397	approx 50 $\mu g/m^3$*
NO_2	0.2	79.4	approx 60 - 100 $\mu g/m^3$*
PM_{10}	0.8	318	21.8 $\mu g/m^3$
TVOC	9.0	3,573	315.1 $\mu g/m^3$*

For Offices:

Substance	ER (Table H-1)	C ($\mu g/m^3$)	Real Levels in offices and public places (Holcomb,1993)
HCHO	0.73	290	approx 50 $\mu g/m^3$*
TVOC	3.3	1,310	315.1 $\mu g/m^3$*

* concentration reported includes all sources, not just ETS

These calculated indoor air concentrations (C) are the minimum which would be expected in a real life situation. They are calculated with minimum ER values (i.e., only a few sources for a given contaminant) and assumed Std. 62-89 ventilation rates. They assume perfect mixing and no outdoor sources. They are also consistently higher than average concentrations actually reported in the literature. This could be due to some combination of the following:

1. Average ventilation rates in U.S. buildings are significantly higher than those specified in Std. 62-89.

2. The AVR equation does not accurately estimate the effect of ventilation on indoor concentrations.

3. The ER values in Table H-1 are unreasonably high.

Since the first explanation is not very likely, the reason seems to be some combination of 2 & 3. Whatever the ultimate reason, the AVR equation and source strengths published in Table H-1 are not acceptable for determining required ventilation rates.

For Consumer Product Emissions: Waxing a Floor.

Substance	ER (Table H-1)	C ($\mu g/m^3$)	Real Levels in offices and public places (Holcomb, 1993)
TVOC	10	3,970	315.1 $\mu g/m^3$*

Required ventilation rate using a target TVOC concentration of 300 $\mu g/m^3$ from Table C-1a:

AVR (l/s-m^3) = 278 X (ER/C) assuming Co and CRA = 0
AVR = 278 X (10/300)
AVR = 9.3 l/s-m^3

at 0.07 persons/m^2

AVR = 132 l/s-p (265 cfm/p)

Required ventilation rate using a target TVOC concentration of 3,000 $\mu g/m^3$ from Table C-1a:

AVR (l/s-m^3) = 278 X (ER/C) assuming Co and CRA = 0
AVR = 278 X (10/3000)
AVR = 0.93 l/s-m^3

at 0.07 persons/m^2

AVR = 13.2 l/s-p (26.5 cfm/p)

Note: Both calculations for floor wax emissions assume the entire office floor is waxed.

References

Holcomb, L.C. 1993. Indoor Air Quality and Environmental Tobacco Smoke: Concentration and Exposure. Environ. Int. 19:9-40.

Appendix B. Conversion Factors

Conversion of ETS from mg/cig to mg/m^2-hr.

Assume 20% of occupants smoke 1 cig/hr.
Occupant density is 7 persons/100 m^2.

$$ER(mg/m^2\text{-hr}) = ER(mg/cig) \times 0.2(smokers/person) \times 0.07(person/m^2) \times 1(cig/smoker\text{-hr})$$

$$ER(mg/m^2\text{-hr}) = ER\ (mg/cig) \times 0.014(cig/m^2\text{-hr})$$

Conversion factors from m^2 of sample to m^2 of floor space; taken from Table H-1.

1. 400 ft^2 of wall space per 144 ft^2 of floor space (2.8:1).
2. 1.3 m^2 of furniture per 1 m^2 of floor space (1.3:1)
3. Smoking rate in the building is that of the average population. 20% of occupants smoking 1 cigarette/hour was chosen.

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